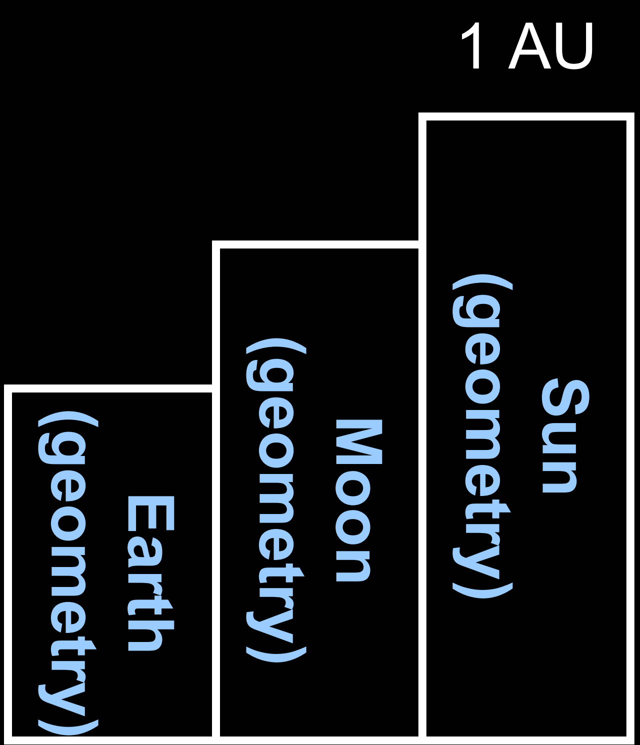
NS102
Lecture 10

The distance ladder

News of the week

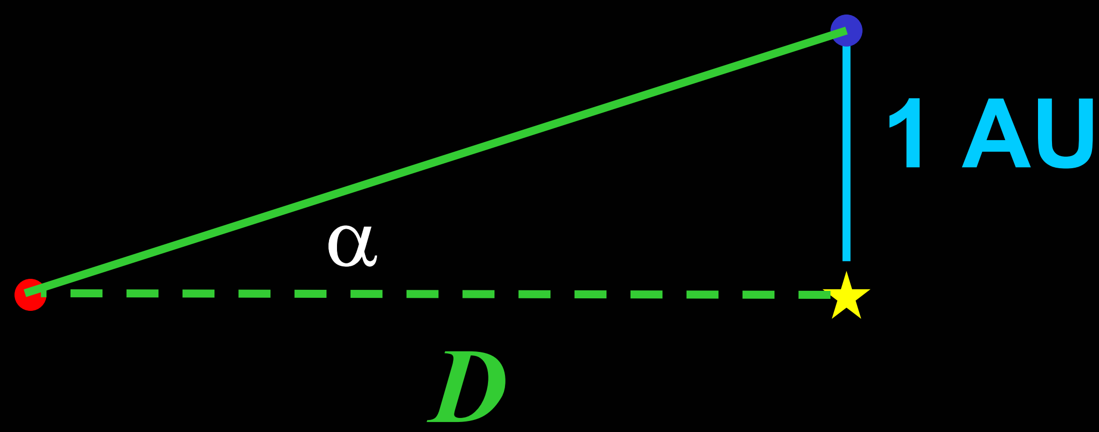
- No office hours on Thursday
- Lab this week: 1st week of geometry of the universe
- Thursday:
  - Shapley-Curtis debate
  - Original composition:
    car horn in G performed by Thao Thai

The Cosmological Distance Ladder



$$\frac{D}{200{,}000\ \text{AU}} = \frac{\text{seconds}}{\text{parallax}}$$

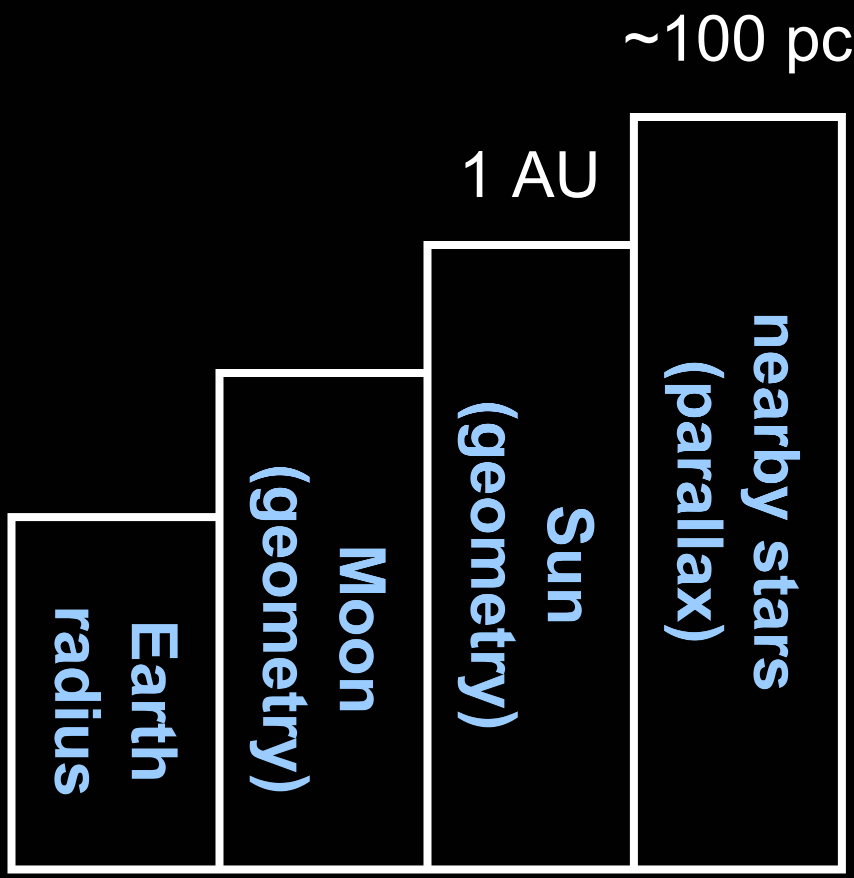
$$\frac{D}{\text{pc}} = \frac{\text{seconds}}{\text{parallax}}$$



$$\frac{D}{\text{pc}} = \frac{\text{seconds}}{\text{parallax}}$$

star	parallax (")	distance (pc)
α Centauri	0.75	1.3
Barnard's star	0.5	2.0
Sirius	0.4	2.5
Altair	0.2	5.0

The Cosmological Distance Ladder



For light!!!

$$\text{Intensity} = \frac{\text{luminosity}}{\text{area}}$$

Luminosity property of source

Intensity depends on power and distance between source and detector (R)

$$\text{Intensity} = \frac{\text{luminosity}}{4\pi R^2}$$

Logarithmic Eye

Eyes, like ears, are logarithmetic detectors.

For light: $$m_1 - m_2 = -2.5\log\left(I_1/I_2\right)$$

$$m = \text{ magnitude} \quad I = \text{ intensity}$$

“–” means smaller *m* is brighter!

Sun	**m = - 26.8**
Venus	**m = - 4**
Sirius	**m = - 1.5**
Naked eye limit	**m = 6**
Binoculars	**m = 10**
Pluto	**m = 15**
Large telescope (visual)	**m = 20**
Large telescope (photograph)	**m = 25**
Large telescope (ccd)	**m = 30**

The luminosity of nearby stars

Measure: intensity of light, I

$$I = \frac{L}{4\pi R^2}$$

If know distance (e.g., parallax) → luminosity

If know luminosity (standard candle) → distance

$$\frac{D}{\text{pc}} = \frac{\text{seconds}}{\text{parallax}}$$

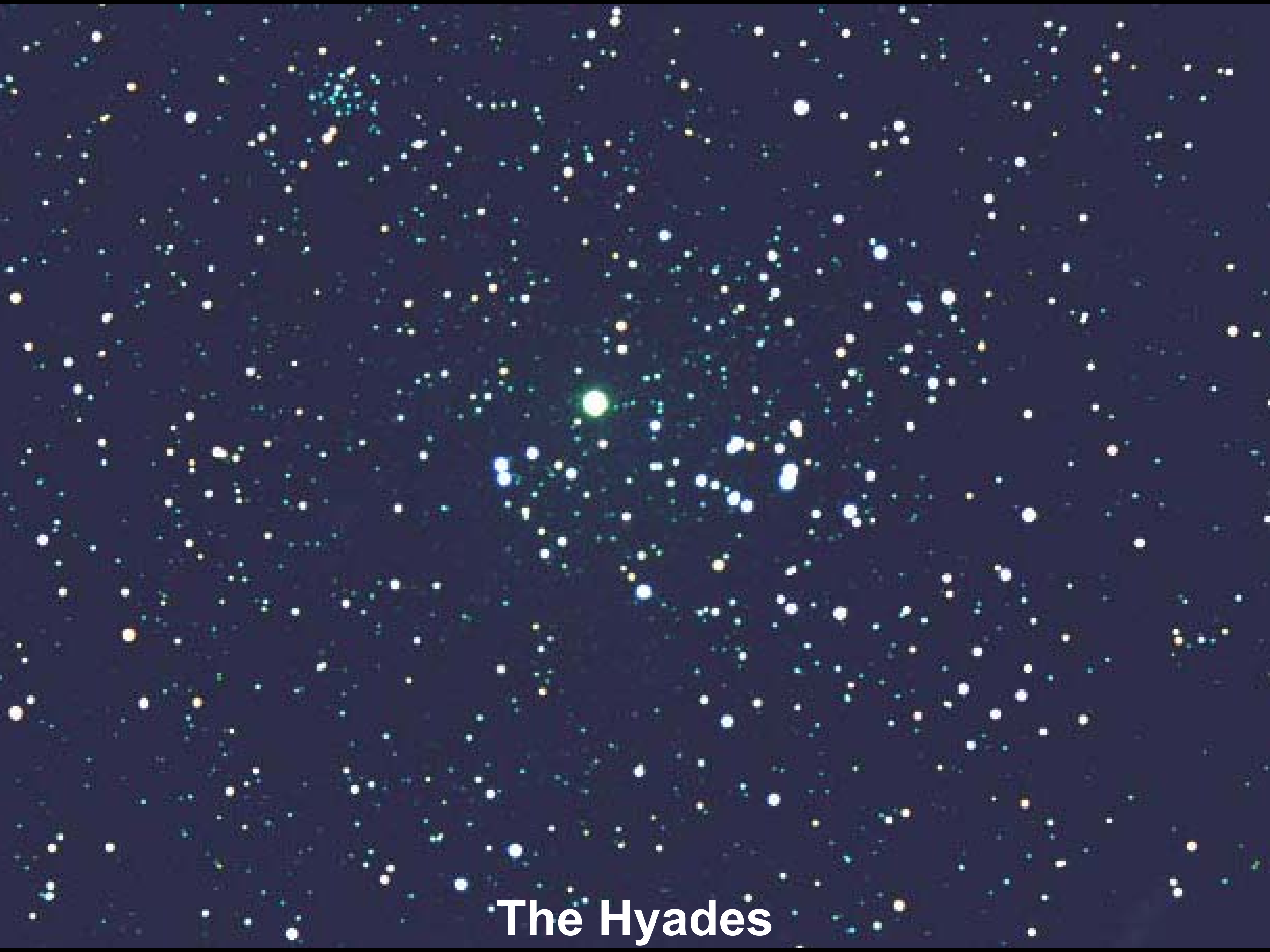
$$I = \frac{L}{4\pi R^2}$$

Measured

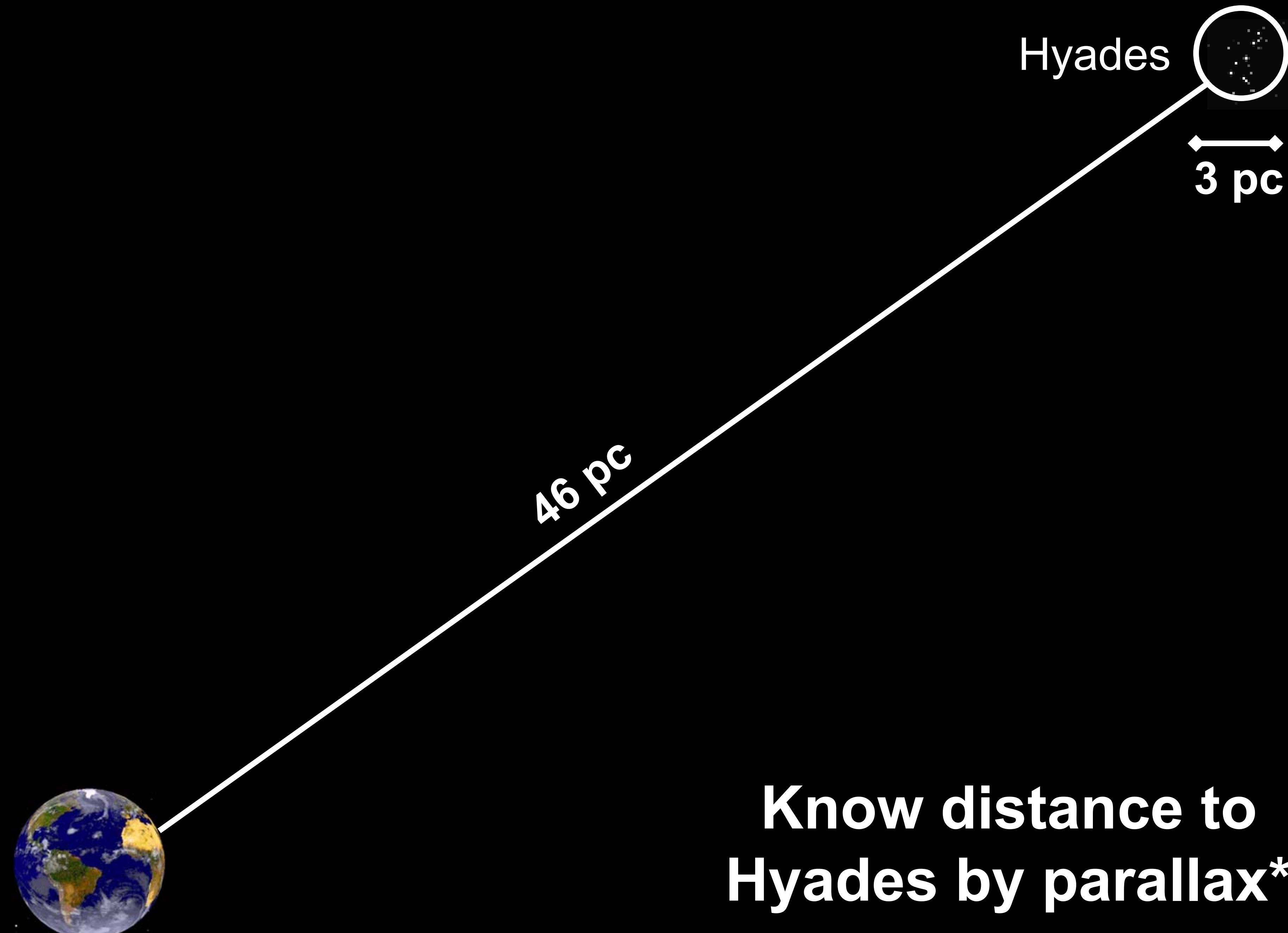
star	parallax (")	distance (pc)	apparent magnitude	luminosity (solar)
α Centauri	0.75	1.3	0	1.5
Barnard's star	0.5	2.0	9.5	0.0005
Sirius	0.4	2.5	-1.5	25
Altair	0.2	5.0	0.8	10
Canopus	0.003	330	- 0.7	200,000
Arcturus	0.1	10	0	90
Betelgeuse	0.01	100	0.5	14,000


Open Cluster (The Pleiades)
135 pc distant


M 45 (Pléiades)
Hyades
© Denis Bergeron 1980



The Hyades



Know distance to Hyades by parallax*

They have different apparent brightness
They have different colors
They move
They change in brightness

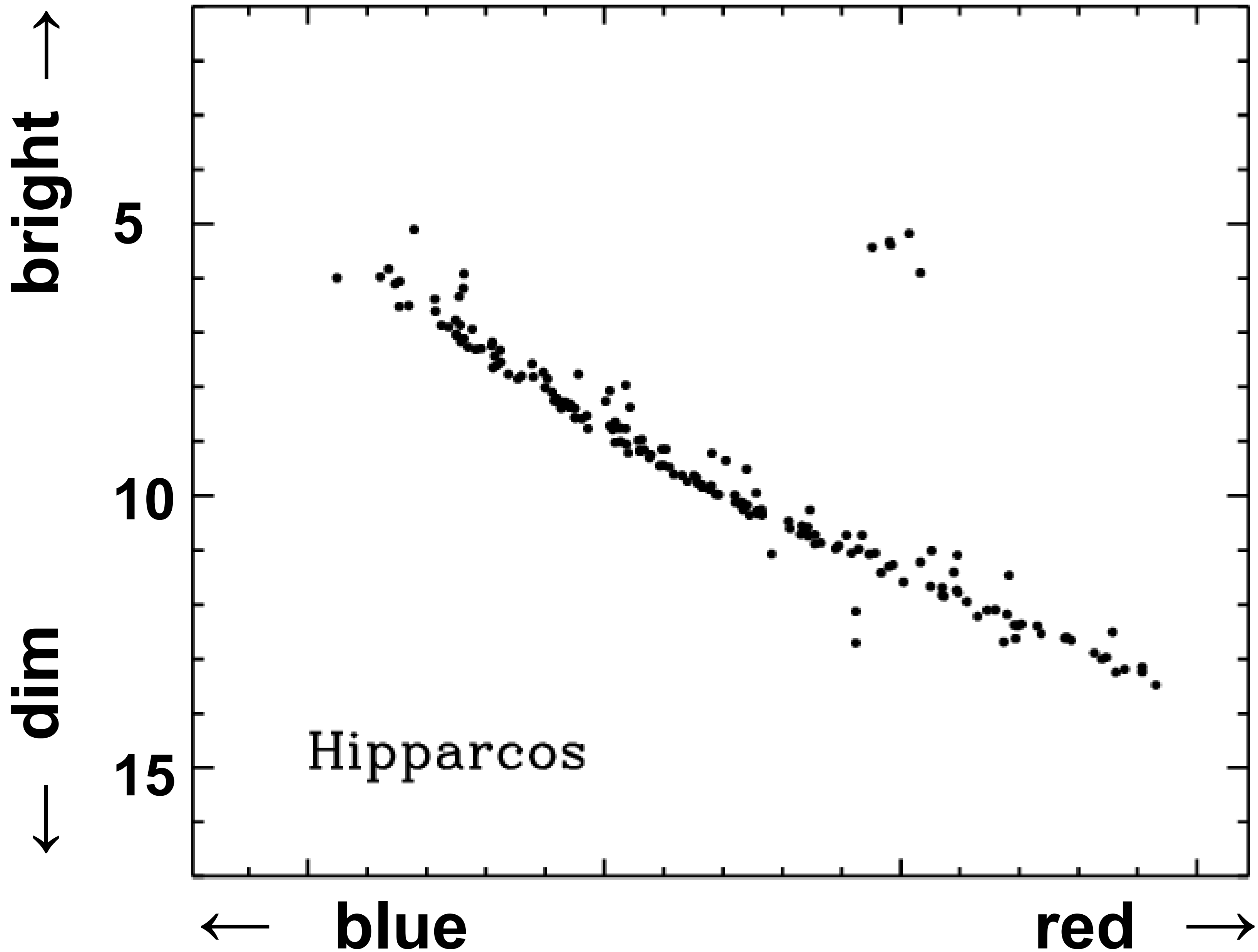
COLORS OF THE RAINBOW:

R O Y – G – B I V

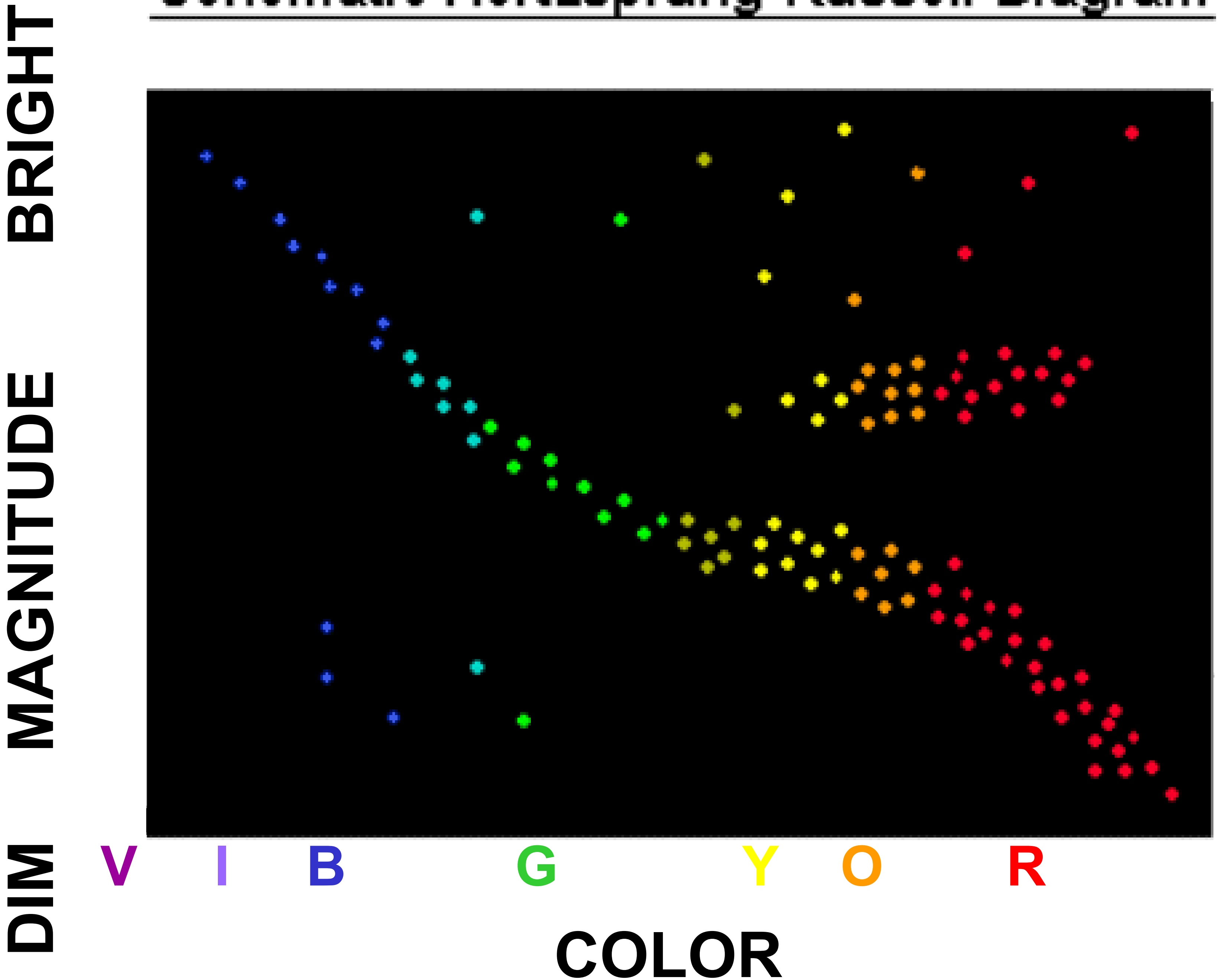

Ejnar Hertzsprung (1873-1967)


Henry Russell (1877-1957)

Hyades HR diagram

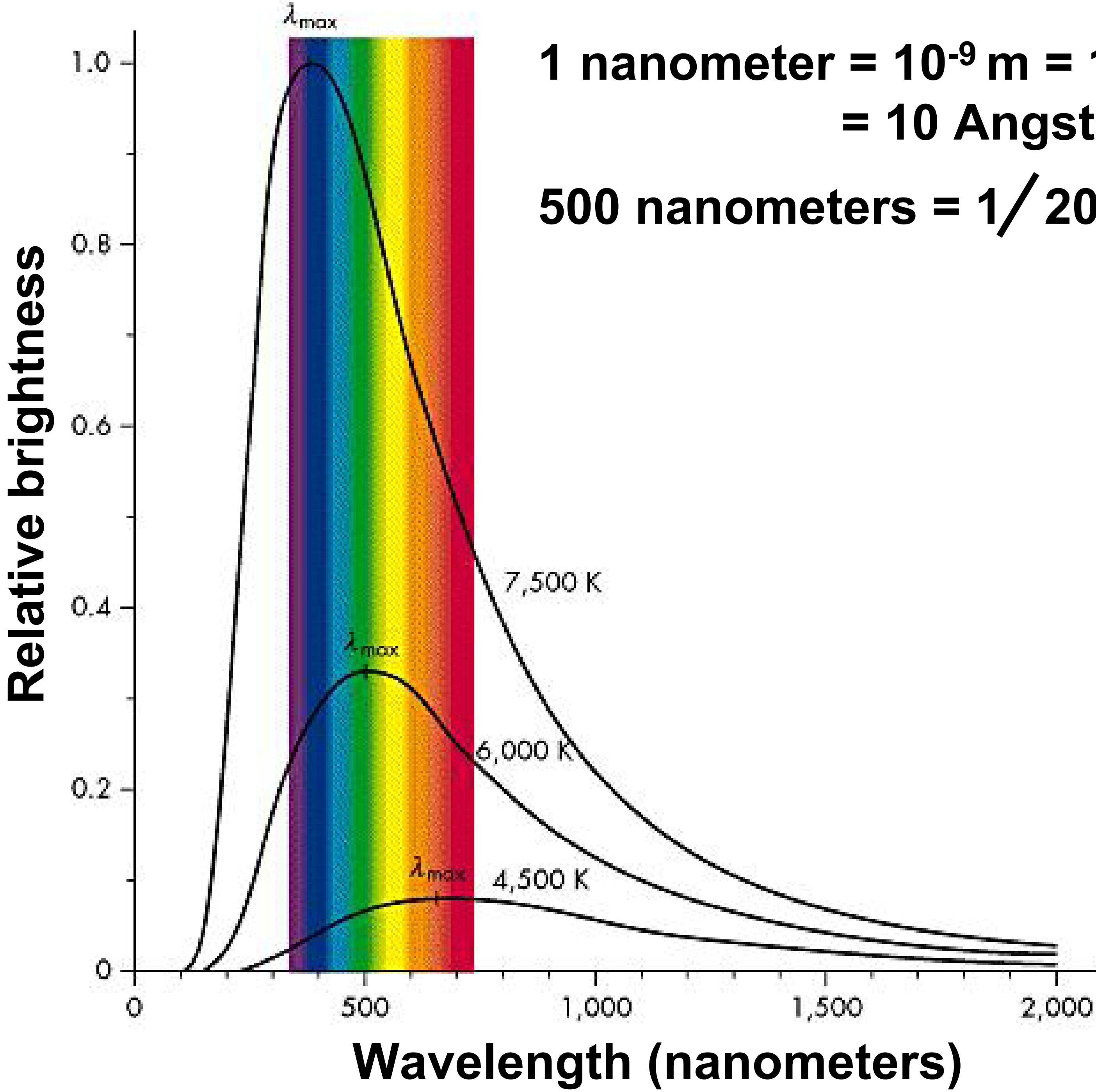


Schematic Hertzsprung-Russell Diagram

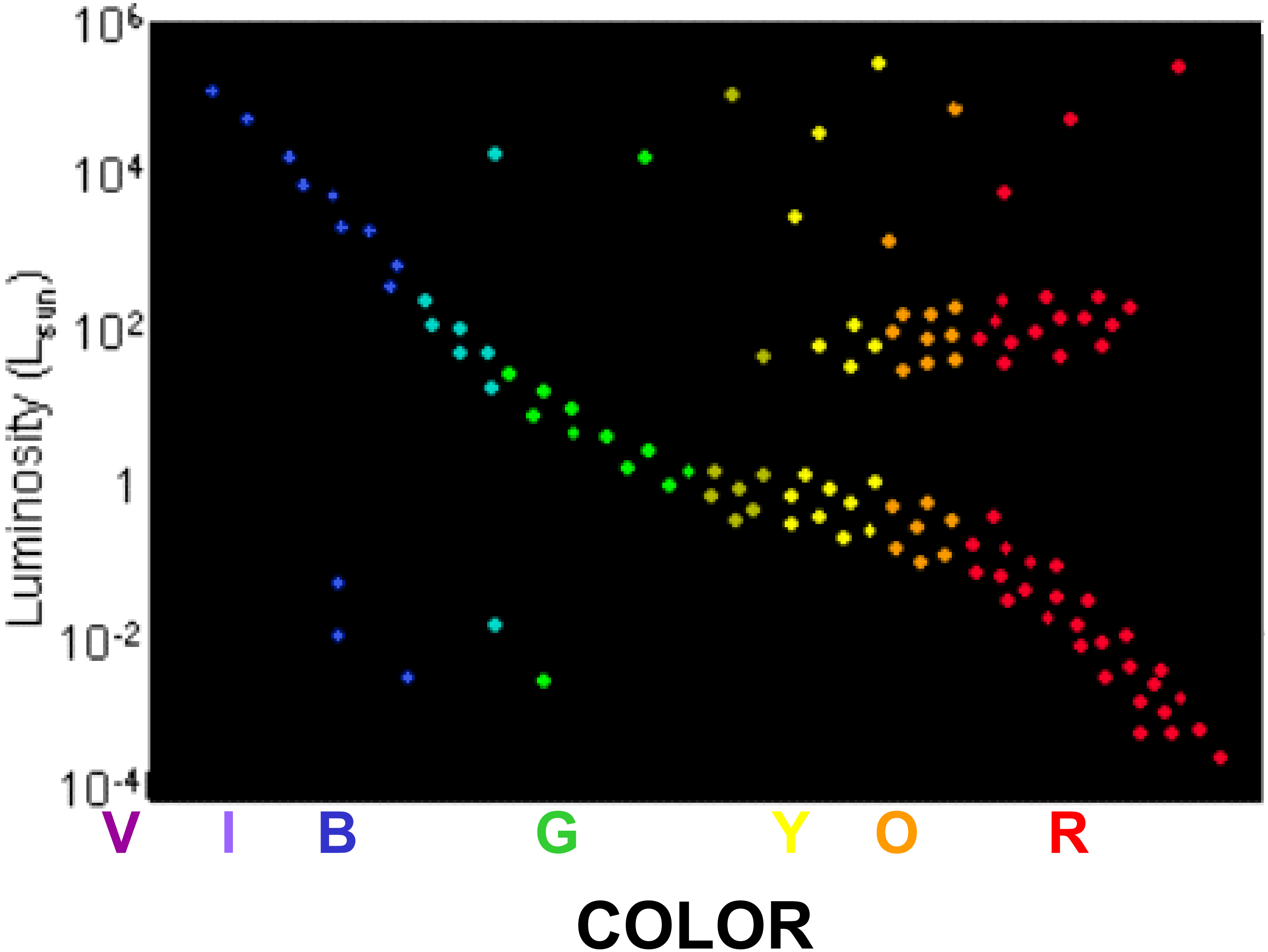


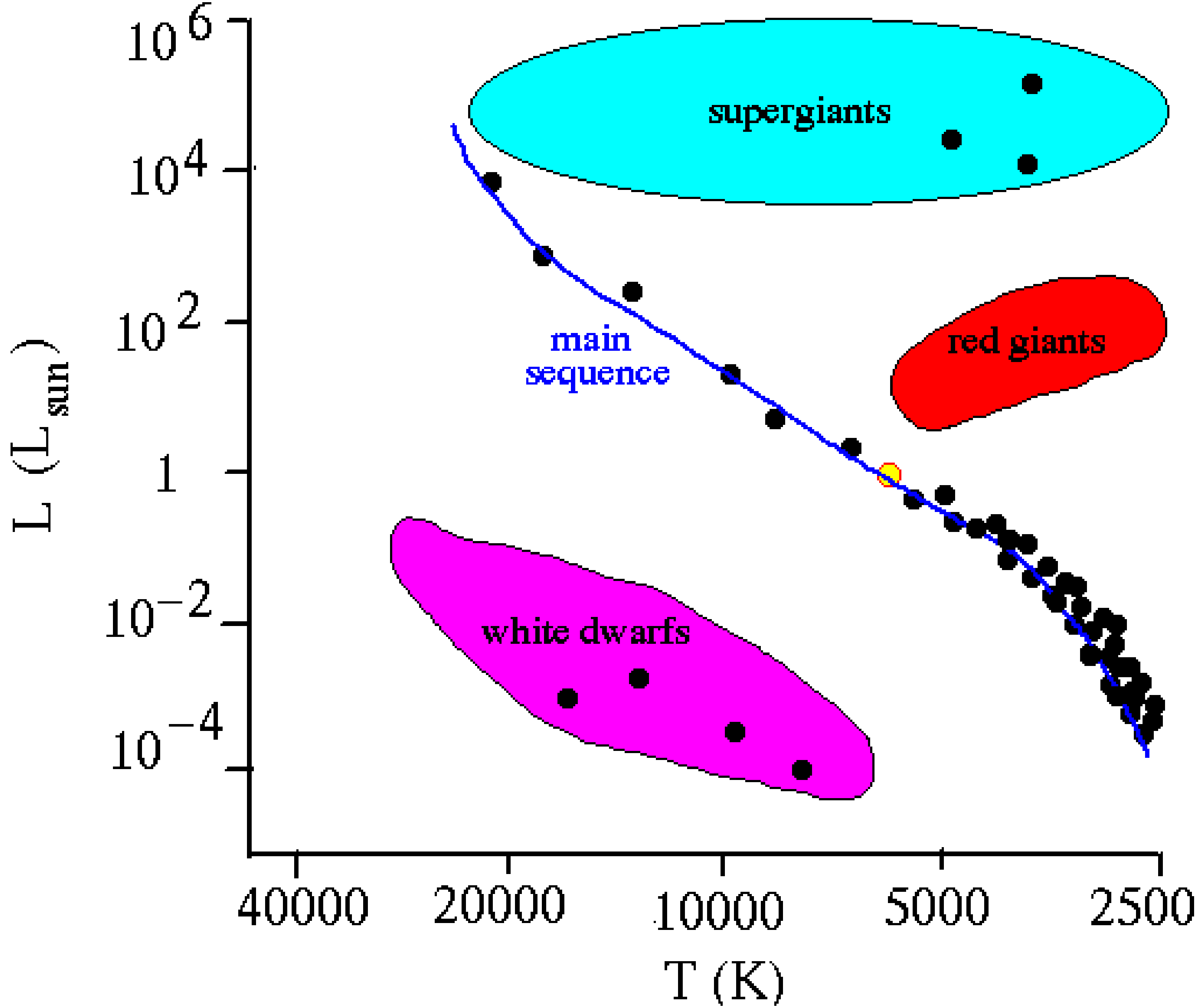
1 nanometer = 10^{-9} m = 10^{-7} cm
= 10 Angstroms

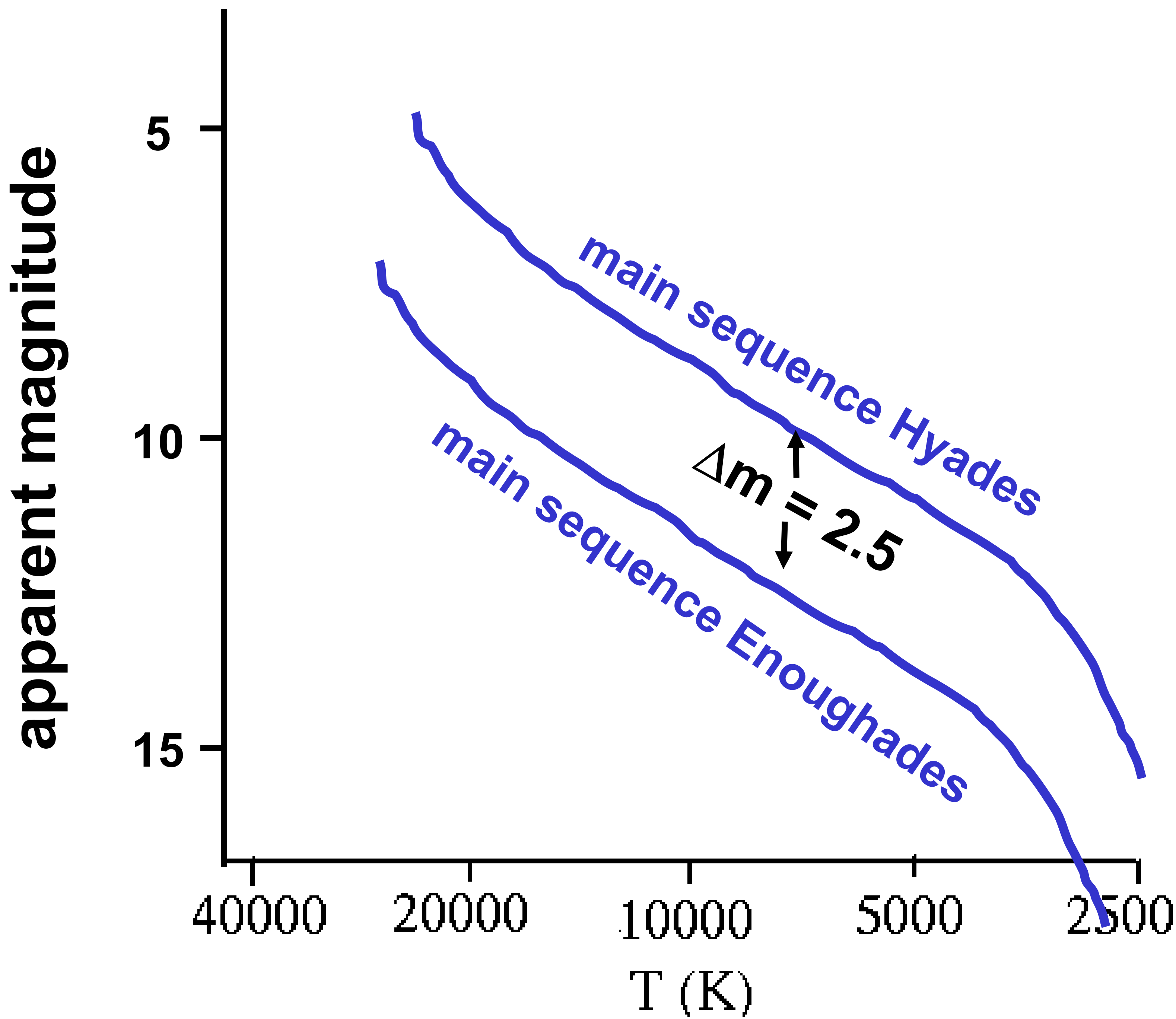
500 nanometers = 1/20,000 cm



Schematic Hertzsprung-Russell Diagram




10^6
10^4
10^2
1
10^{-2}
10^{-4}
$L\ (L_{sun})$
supergiants
red giants
main sequence
white dwarfs
40000
20000
10000
5000
2500
T (K)



apparent magnitude
5
10
15
40000
20000
10000
5000
2500
T (K)
main sequence Hyades
main sequence Enoughades
Δm = 2.5

$$m_H - m_E = -2.5\log\left(I_H / I_E\right)$$

$$-2.5 = -2.5\log\left(I_H / I_E\right)$$

$$1 = \log\left(I_H / I_E\right)$$

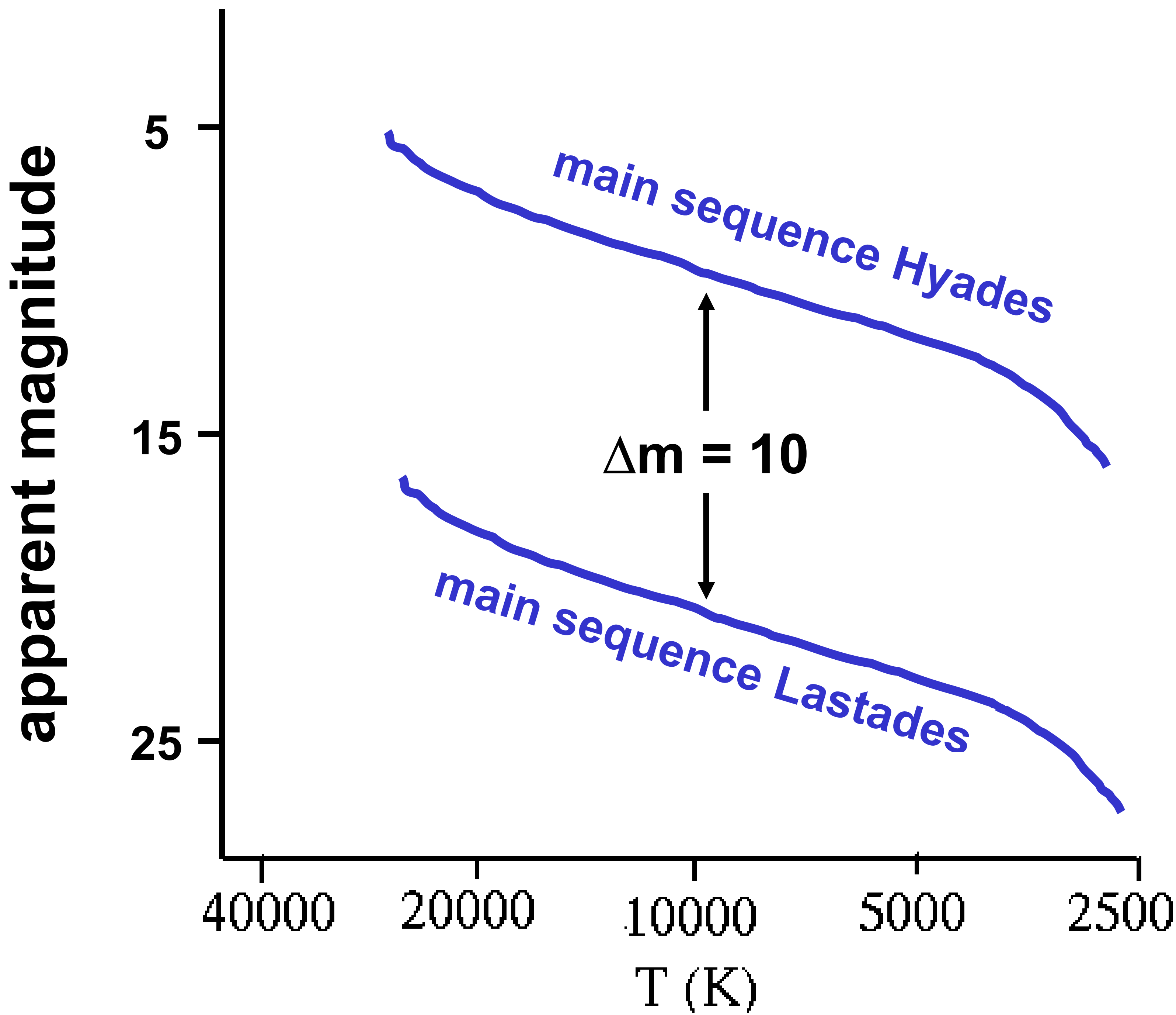
$$10 = I_H / I_E$$

$$I_H = \frac{\text{Luminosity}_H}{4\pi R_H^2} \qquad I_E = \frac{\text{Luminosity}_E}{4\pi R_E^2}$$

$$\frac{I_H}{I_E} = \frac{R_E^2}{R_H^2} \qquad 10 = \frac{R_E^2}{R_H^2} \qquad 3 = \frac{R_E}{R_H}$$

Distances to other clusters

- Construct H-R diagram for cluster
- Measure Δm compared to HR diagram for Hyades
- Compute distance in terms of distance to Hyades
- How far can you go?
- Say most distant open observable cluster is Lastades


apparent magnitude
5
15
25
main sequence Hyades
Δm = 10
main sequence Lastades
40000
20000
10000
5000
2500
T (K)

$$m_H - m_L = -2.5\log\left(I_H / I_L\right)$$

$$-10 = -2.5\log\left(I_H / I_L\right)$$

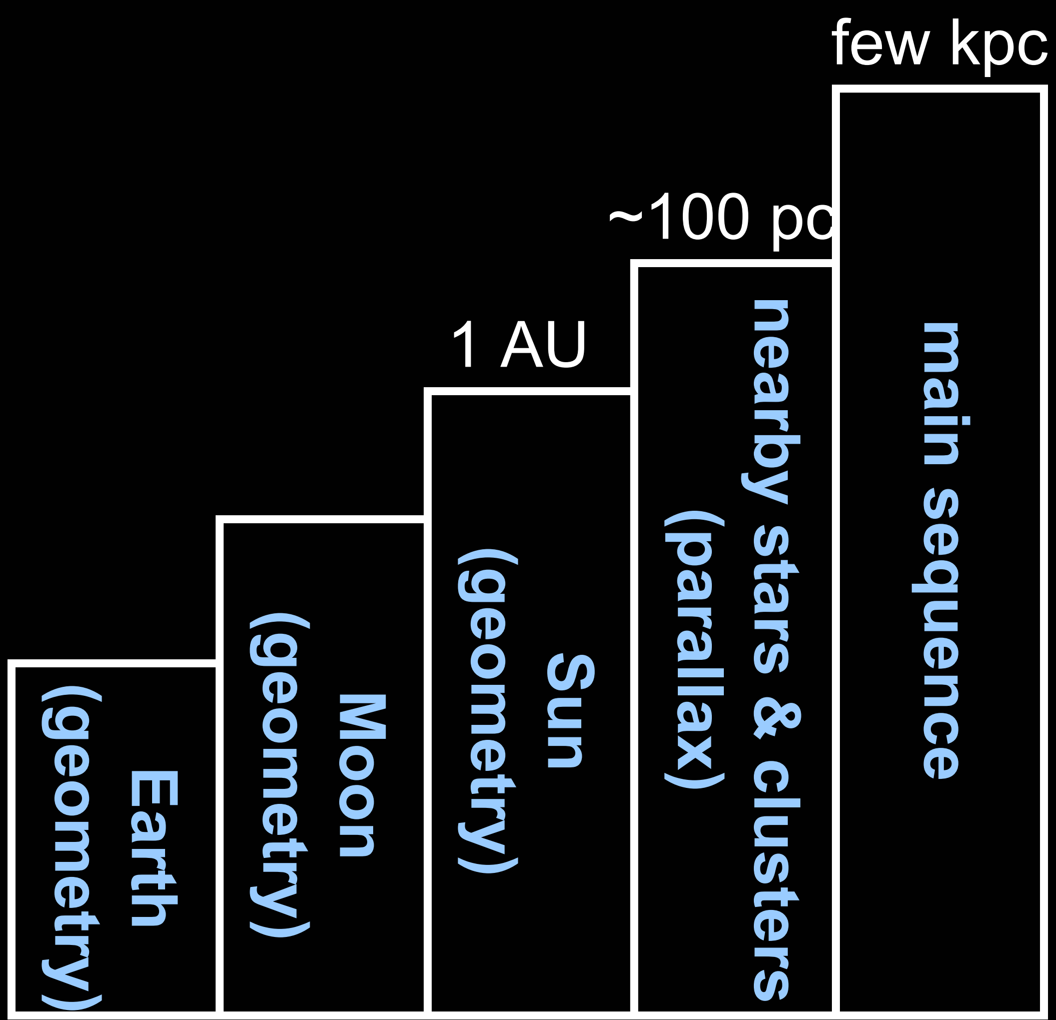
$$4 = \log\left(I_H / I_L\right)$$

$$10^4 = I_H / I_L$$

$$I_H = \frac{\text{Luminosity}_H}{4\pi R_H^2} \qquad I_L = \frac{\text{Luminosity}_L}{4\pi R_L^2}$$

$$\frac{I_H}{I_L} = \frac{R_L^2}{R_H^2} \qquad 10^4 = \frac{R_L^2}{R_H^2} \qquad 100 = \frac{R_L}{R_H} \qquad 4\,\text{kpc} = R_L$$

The Cosmological Distance Ladder



• Main sequence stars are not extremely bright… we need brighter "standard candle"

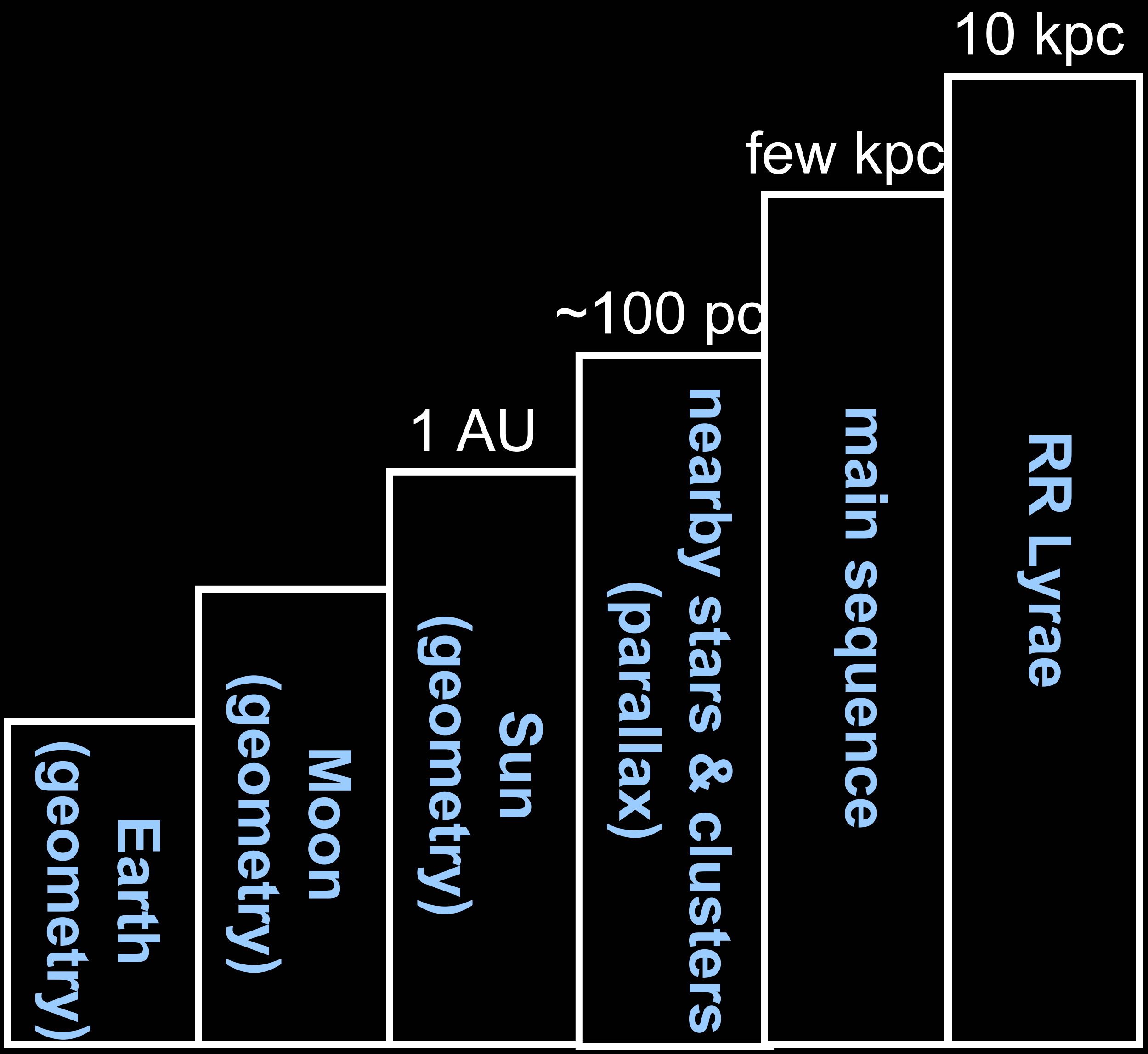
$$\text{Intensity} = \frac{\text{Luminosity}}{4\pi R^2}$$

• RR Lyrae stars found in distant clusters we know the distance to via H-R fitting.

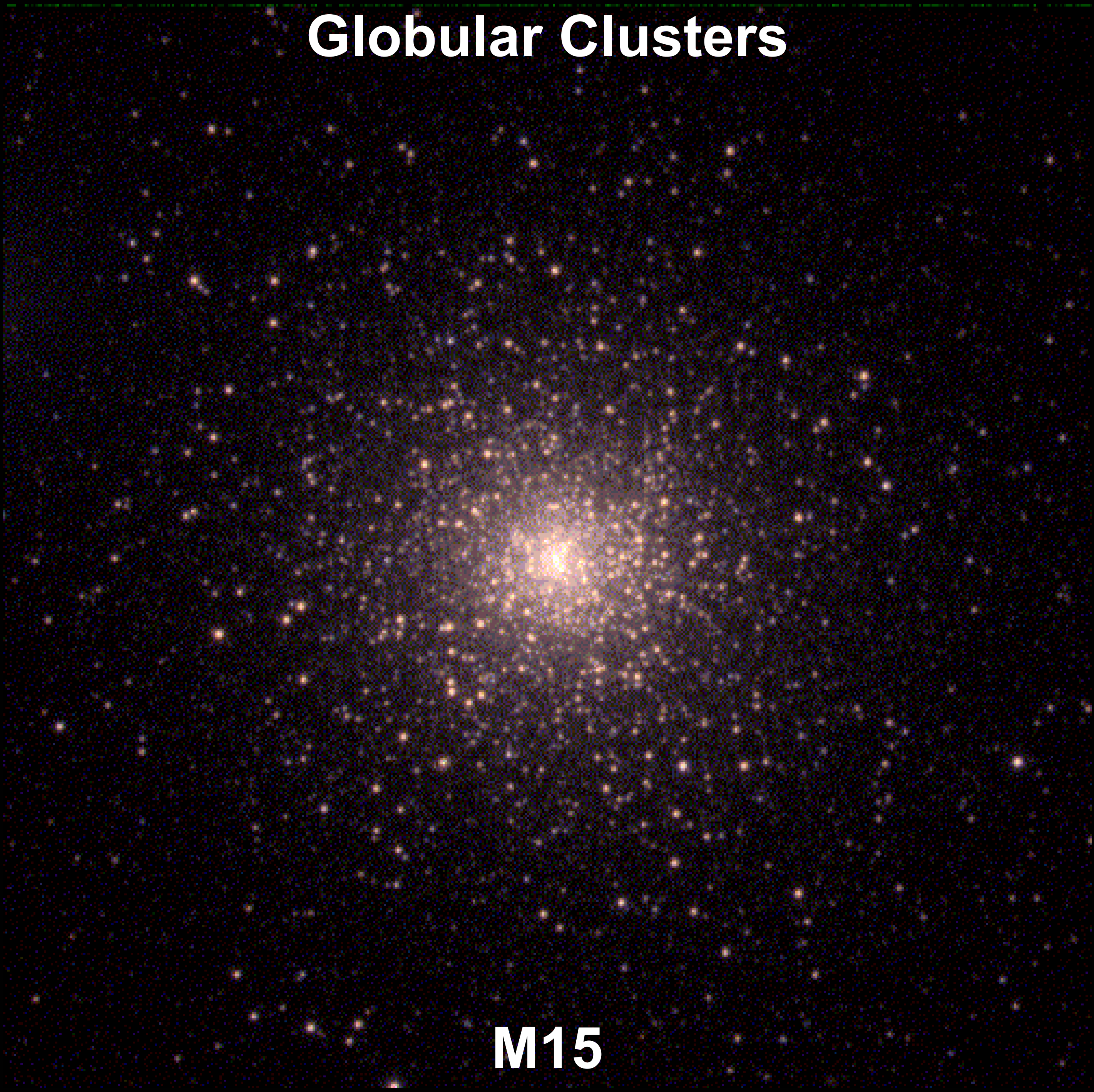
• RR Lyrae stars are identified because their light output changes regularly on a time scale of half to one day.

• They are brighter than the sun by about a factor of 100 and are <u>standard candles</u>. Can see farther away and use as standard candle.

The Cosmological Distance Ladder



Globular Clusters



They have different apparent brightness
They have different colors
They move
They change in brightness

• Need brighter "standard candle"

$$\text{Intensity} = \frac{\text{Luminosity}}{4\pi R^2}$$

• Other variable stars are brighter: Cepheid Stars

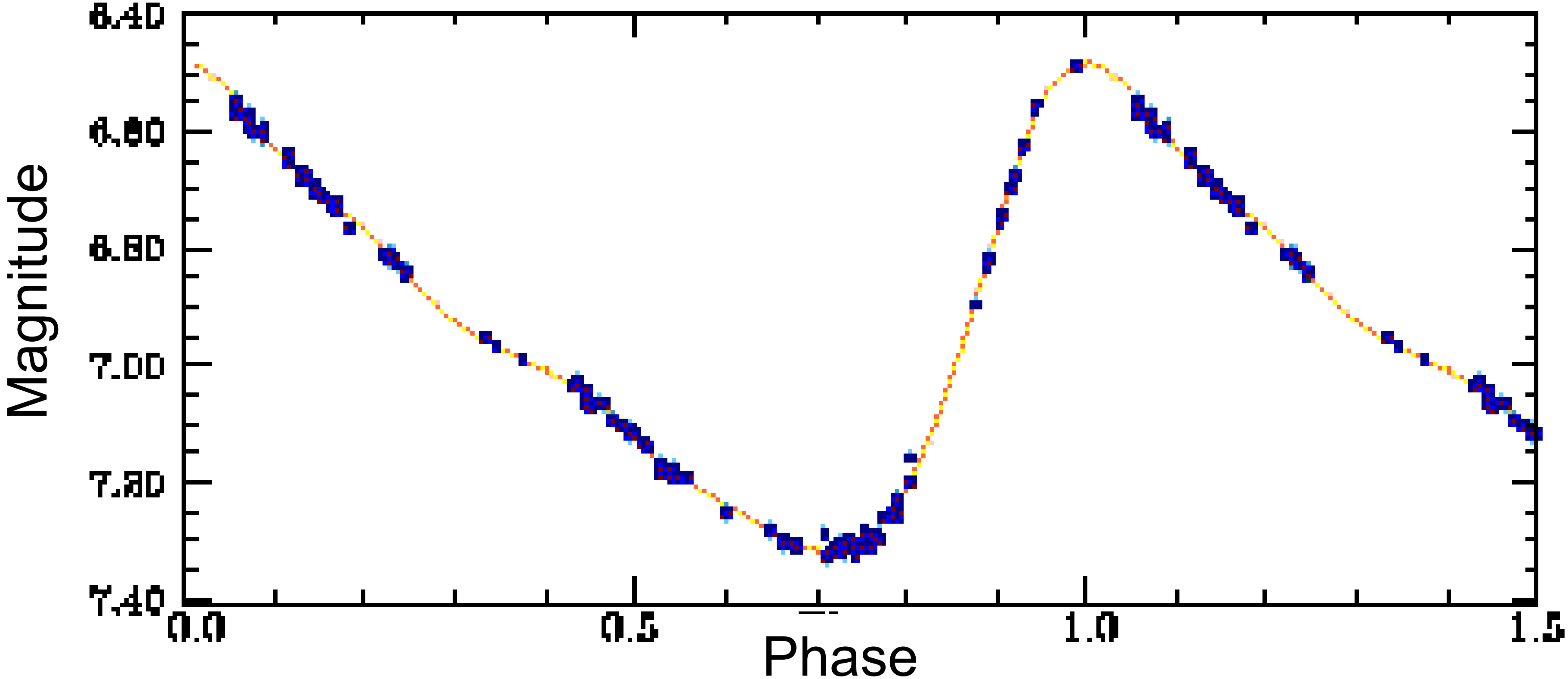
(Polaris is a Cepheid)

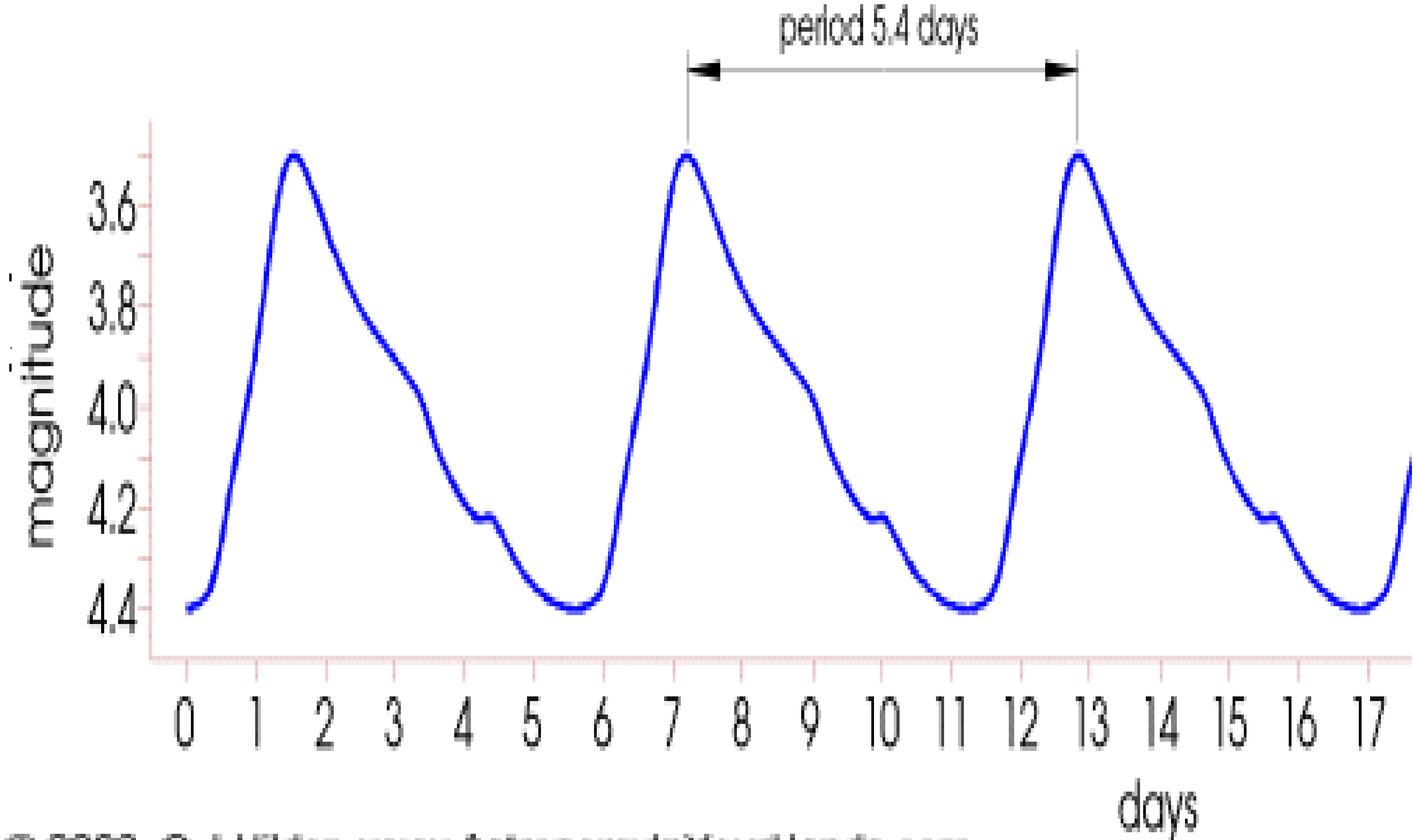
• Cepheid stars are identified because their light output changes regularly on a time scale of weeks to months. They are very rare.

• They are brighter than the sun by about a factor of 10,000 but are not standard candles.

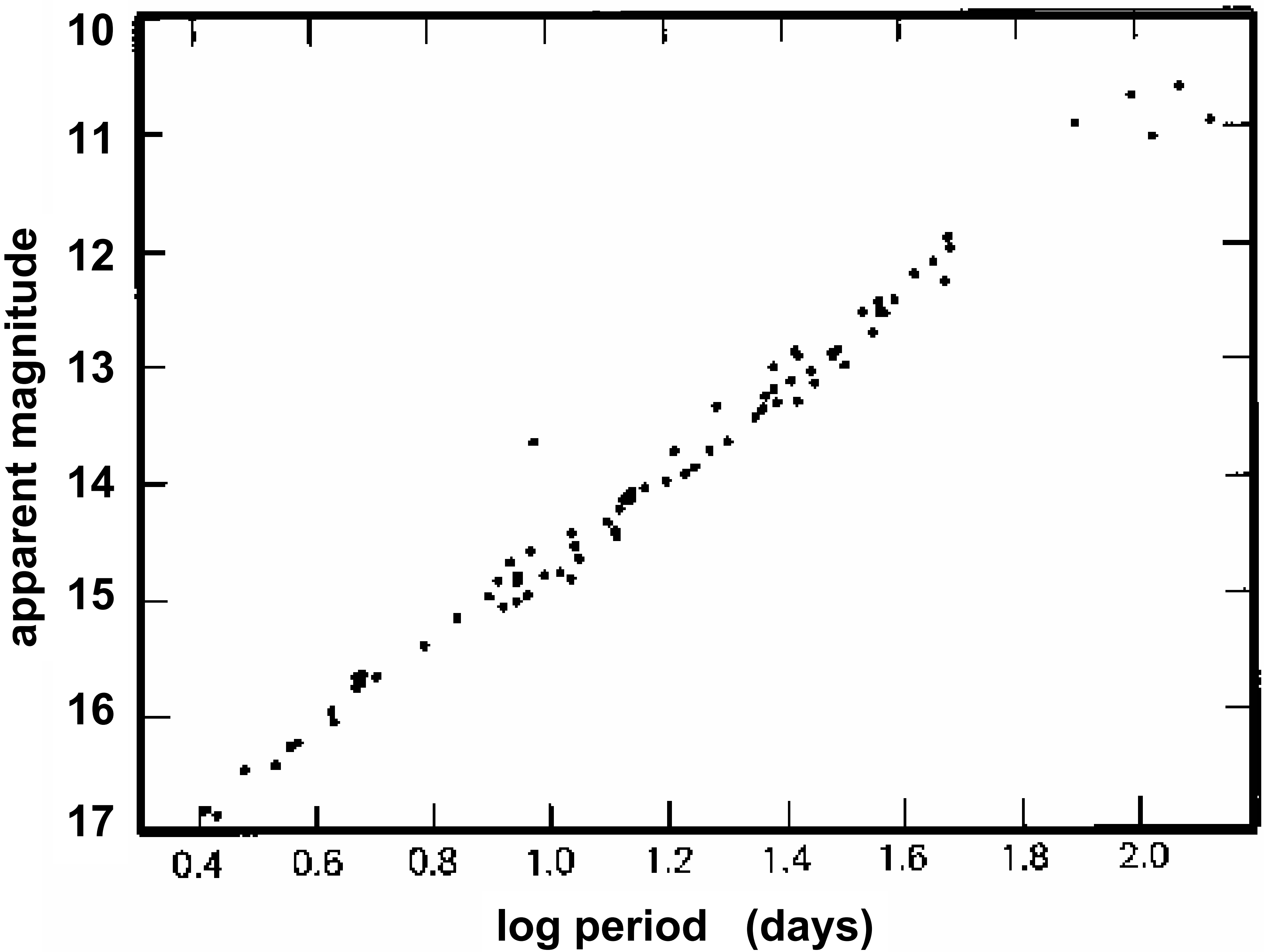
Cepheid Variable Stars

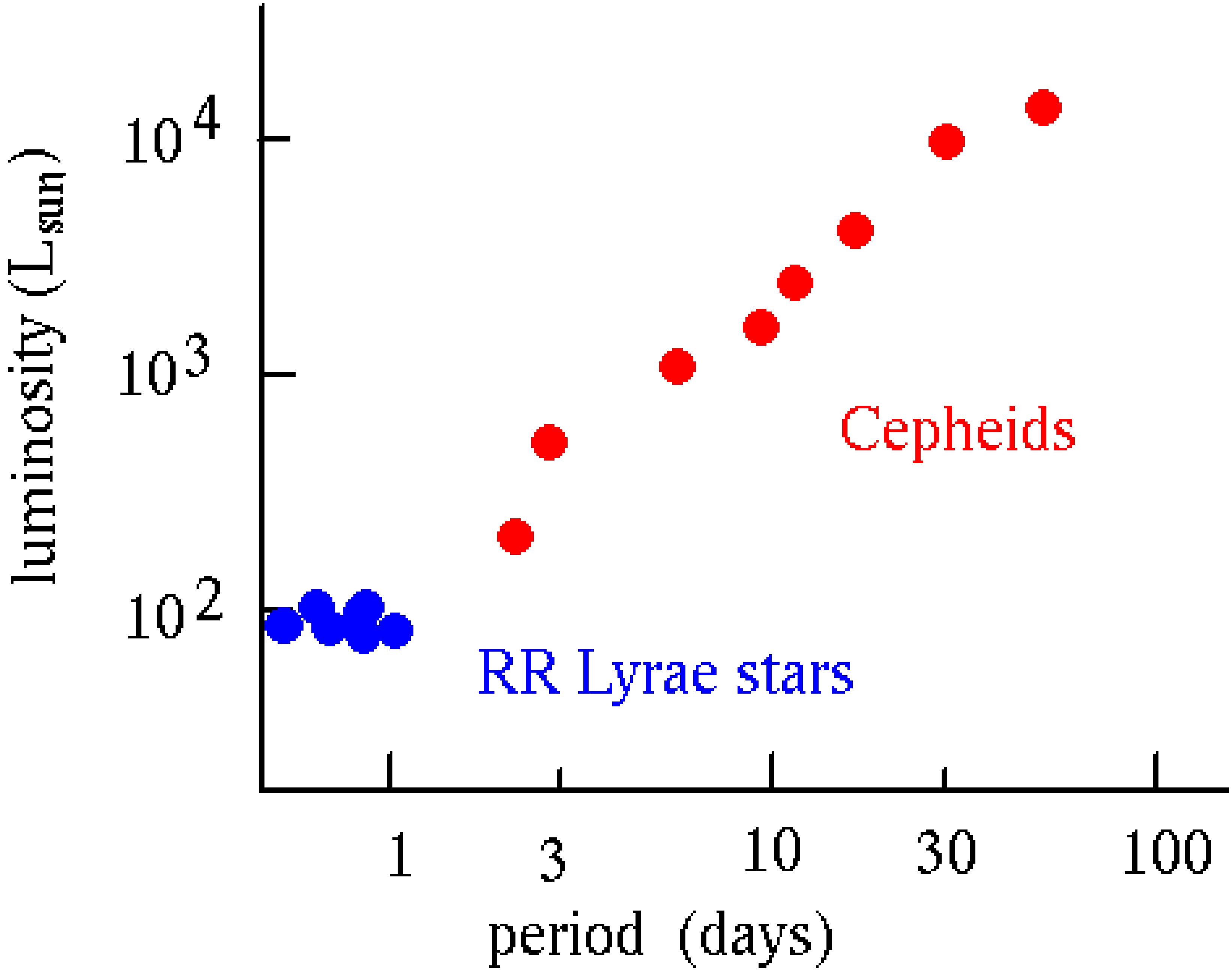
Henrietta Leavitt
1868 - 1921


6.40
6.60
6.80
7.00
7.20
7.40
0.0
0.5
1.0
1.5
Magnitude
Phase



Light curve of Delta Cephei


apparent magnitude
10
11
12
13
14
15
16
17
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
log period (days)



luminosity (L_{sun})
10^4
10^3
10^2
Cepheids
RR Lyrae stars
1
3
10
30
100
period (days)

Cepheids as distance indicators

For cepheids of known distance

- Measure apparent magnitude of the cepheids

$$I = \frac{L}{4\pi R^2} \quad \rightarrow \text{know } L$$

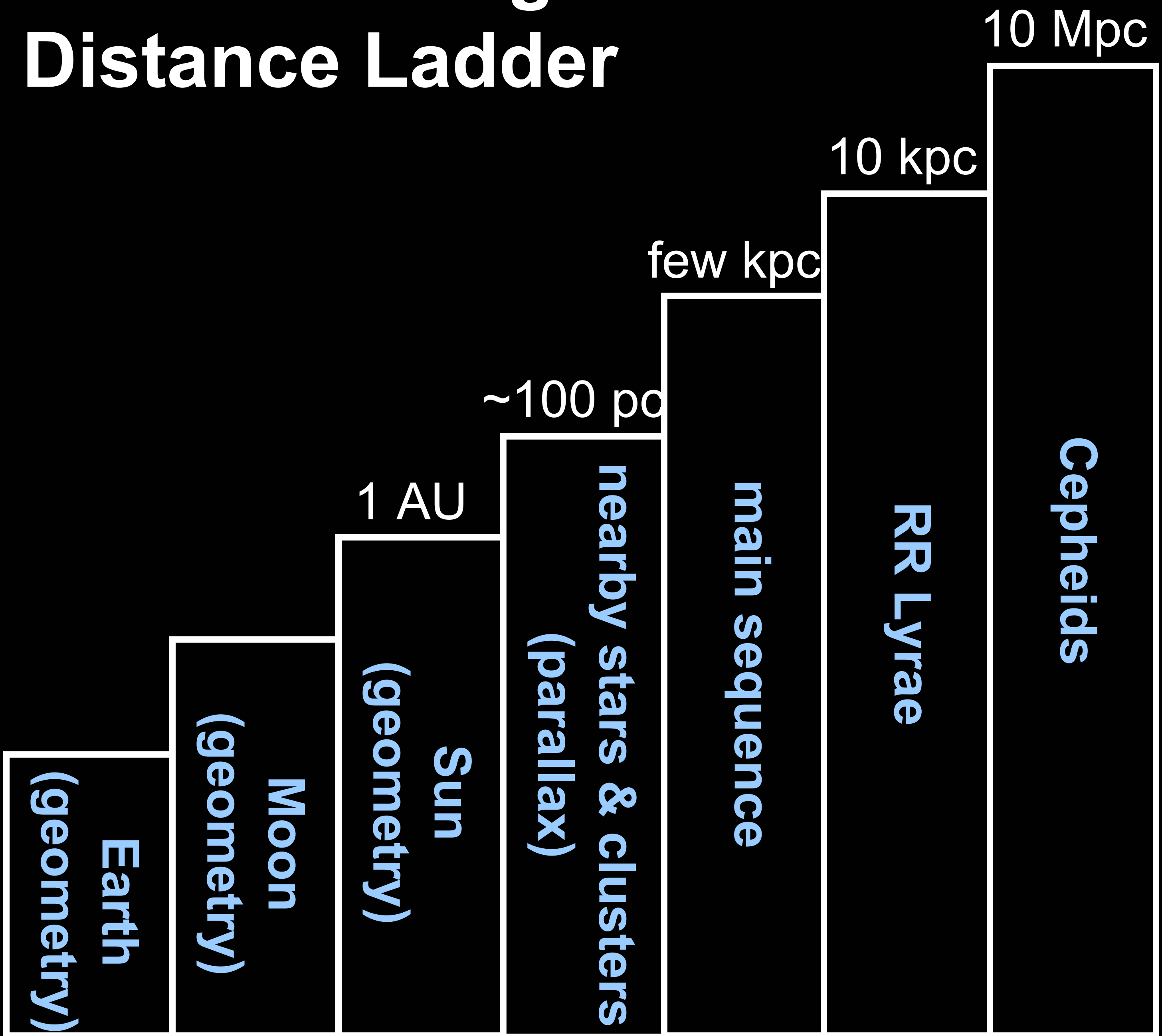
- Measure period of the cepheids
- Calibrate (if know period know L)

For cepheids of unknown distance

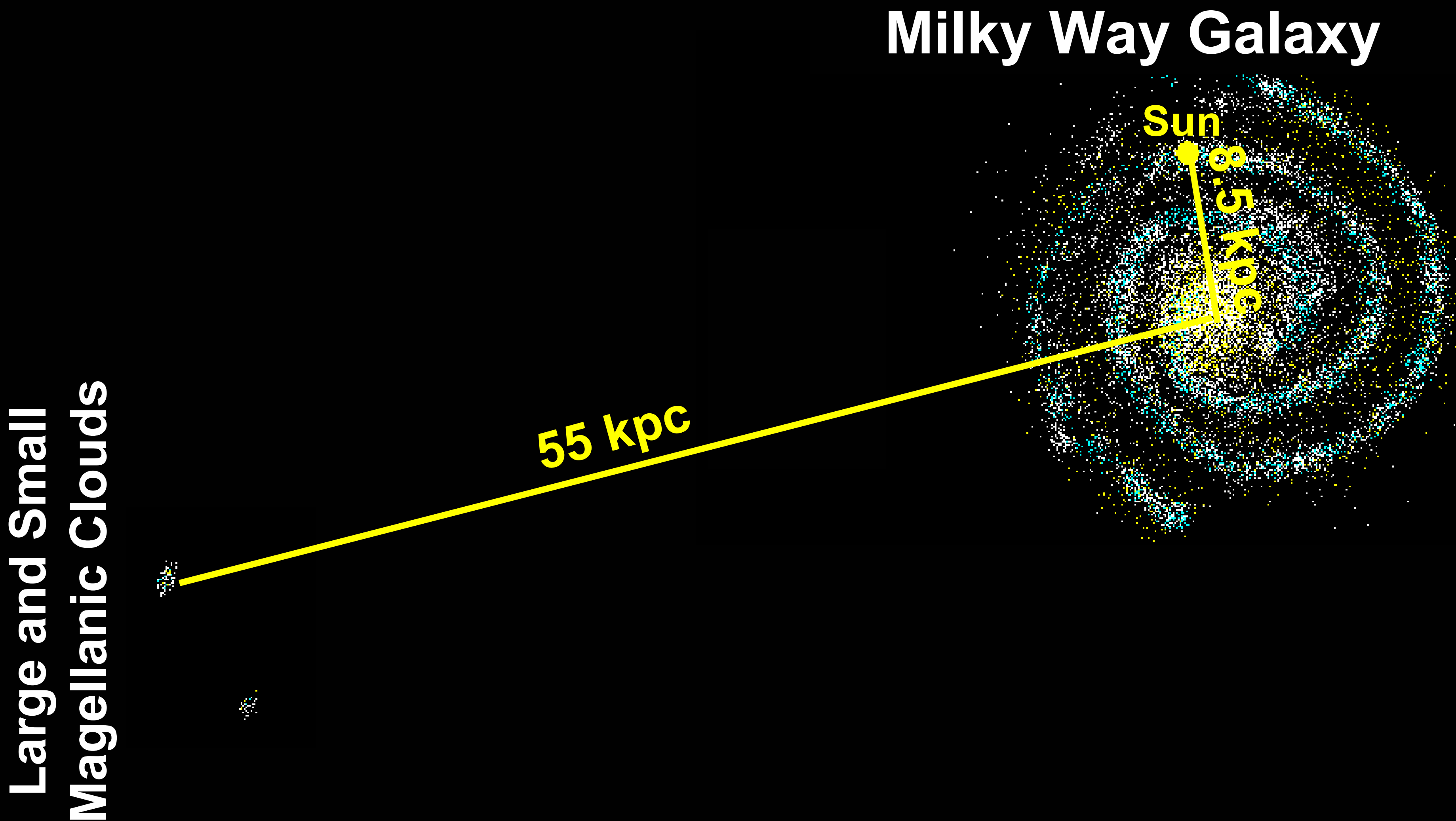
- Measure period….know L
- Measure apparent magnitude

$$I = \frac{L}{4\pi R^2} \quad \rightarrow \text{know } R$$

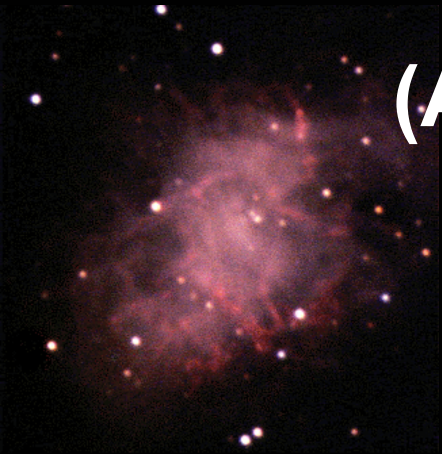
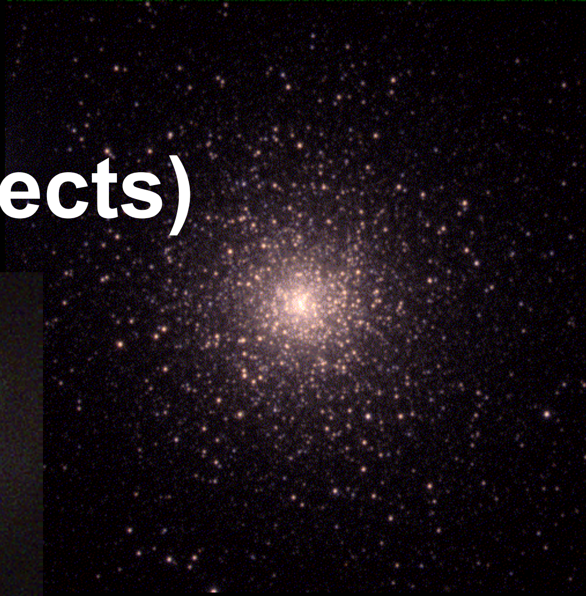
The Cosmological Distance Ladder



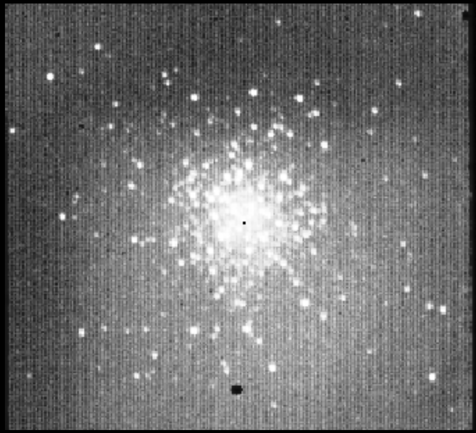
Large Magellanic Cloud   100 million stars   55 kpc distant

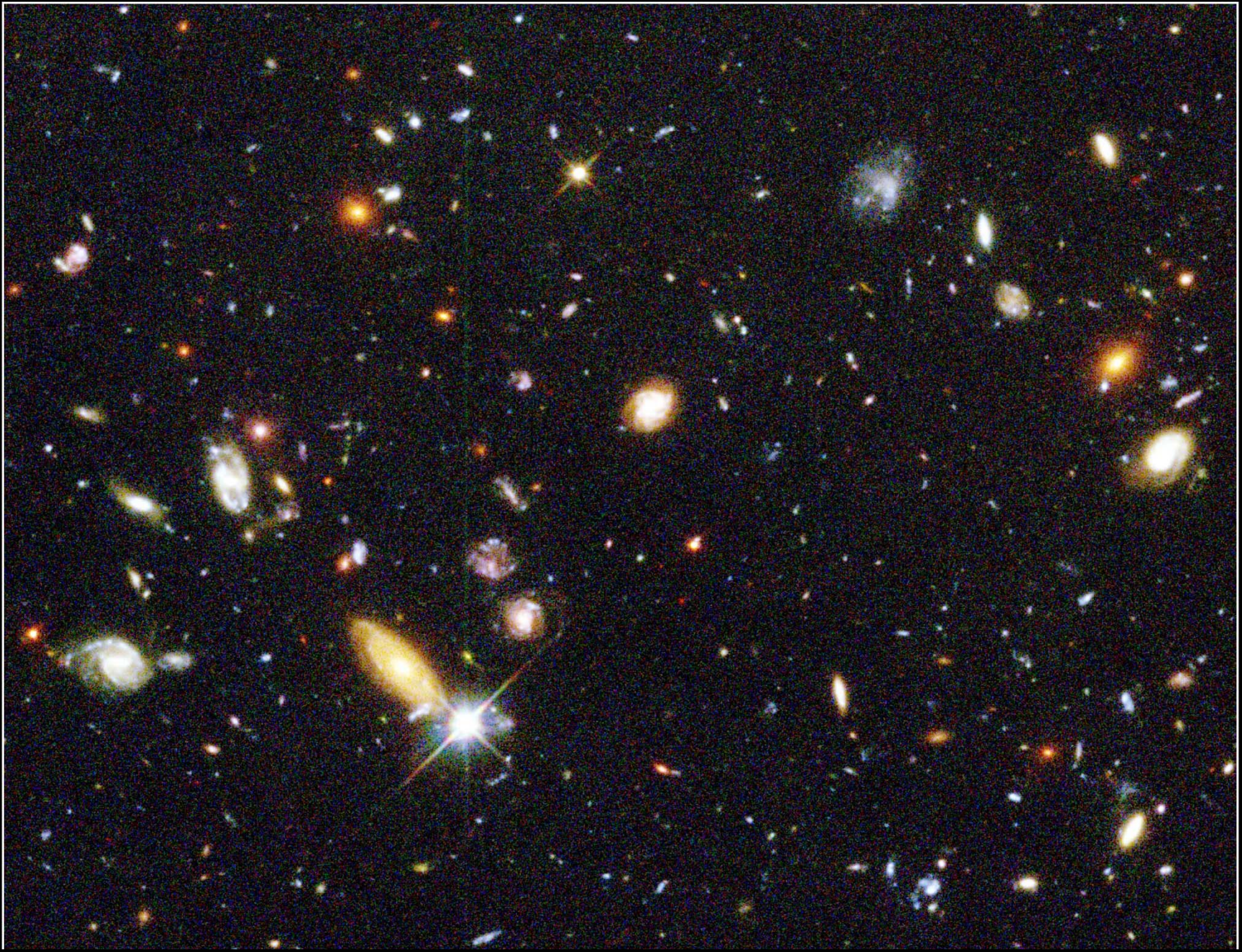

Milky Way Galaxy
Sun
8.5 kpc
55 kpc
Large and Small
Magellanic Clouds

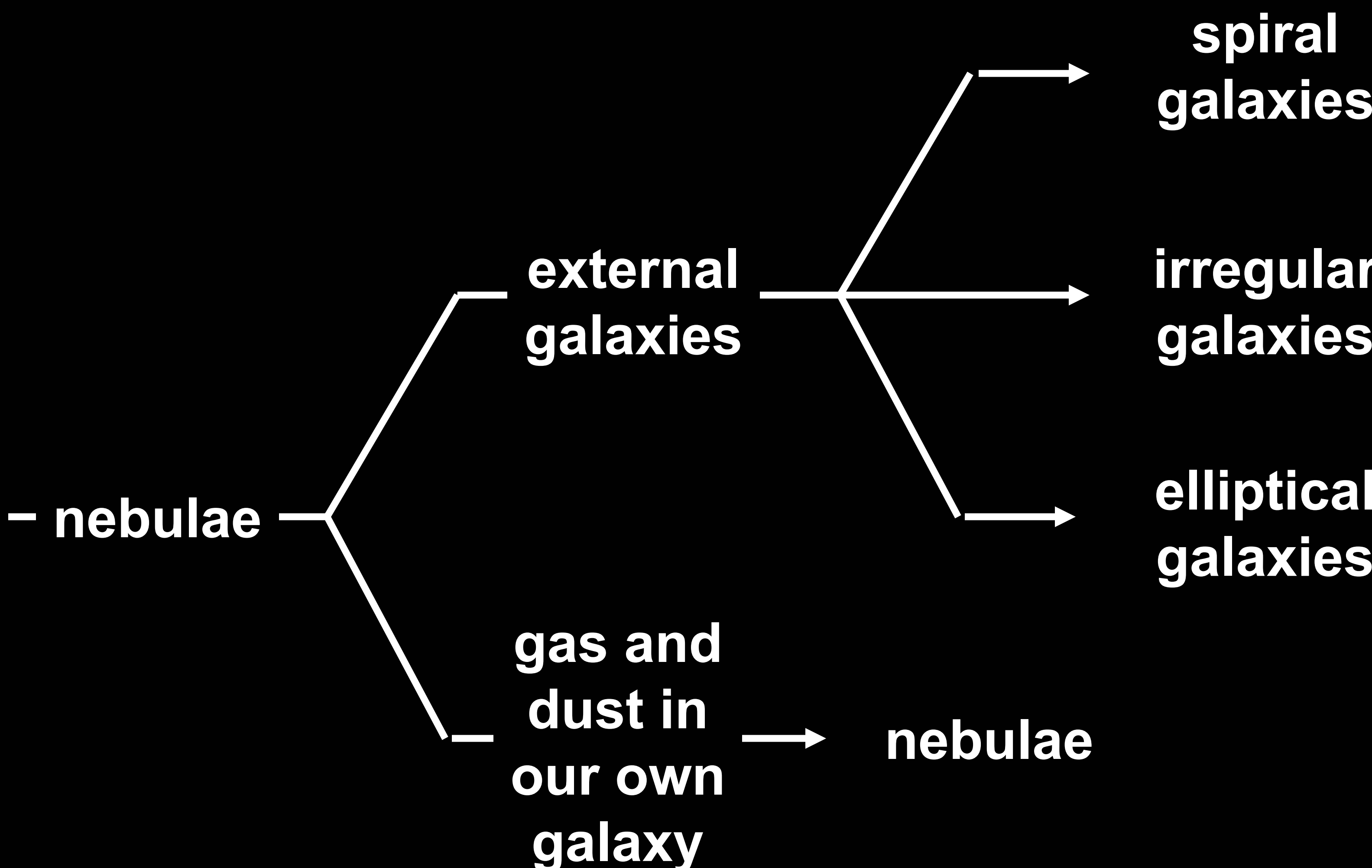
Clouds in the Sky
(A Mess of Messier Objects)



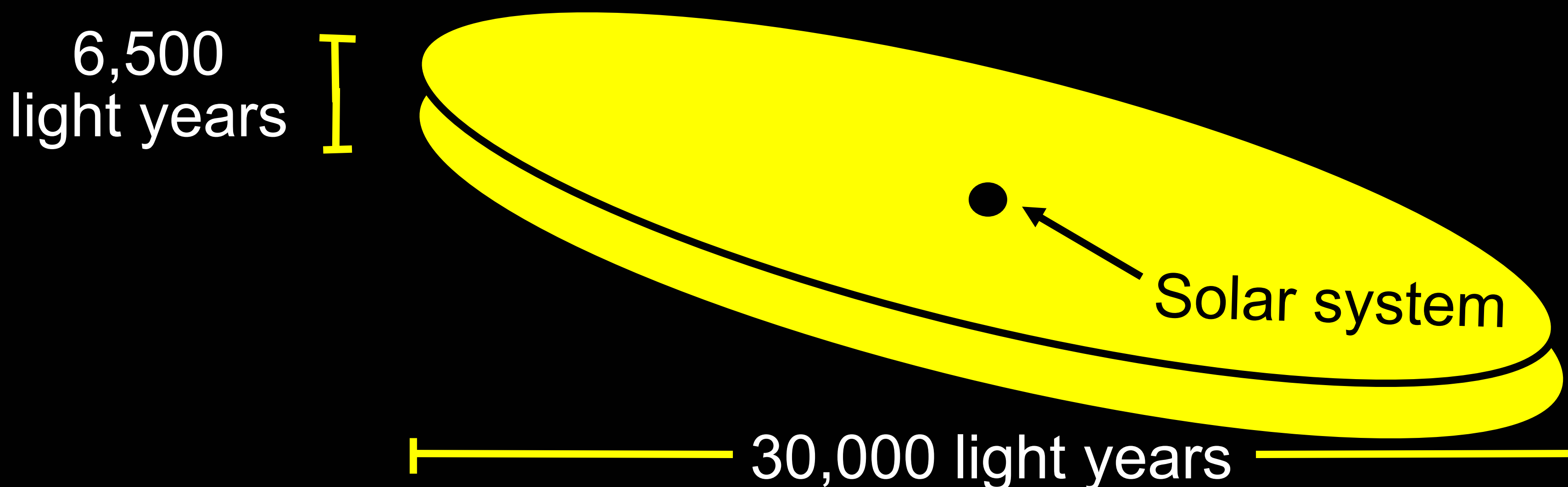


nebulae
external galaxies
spiral galaxies
irregular galaxies
elliptical galaxies
gas and dust in our own galaxy
nebulae

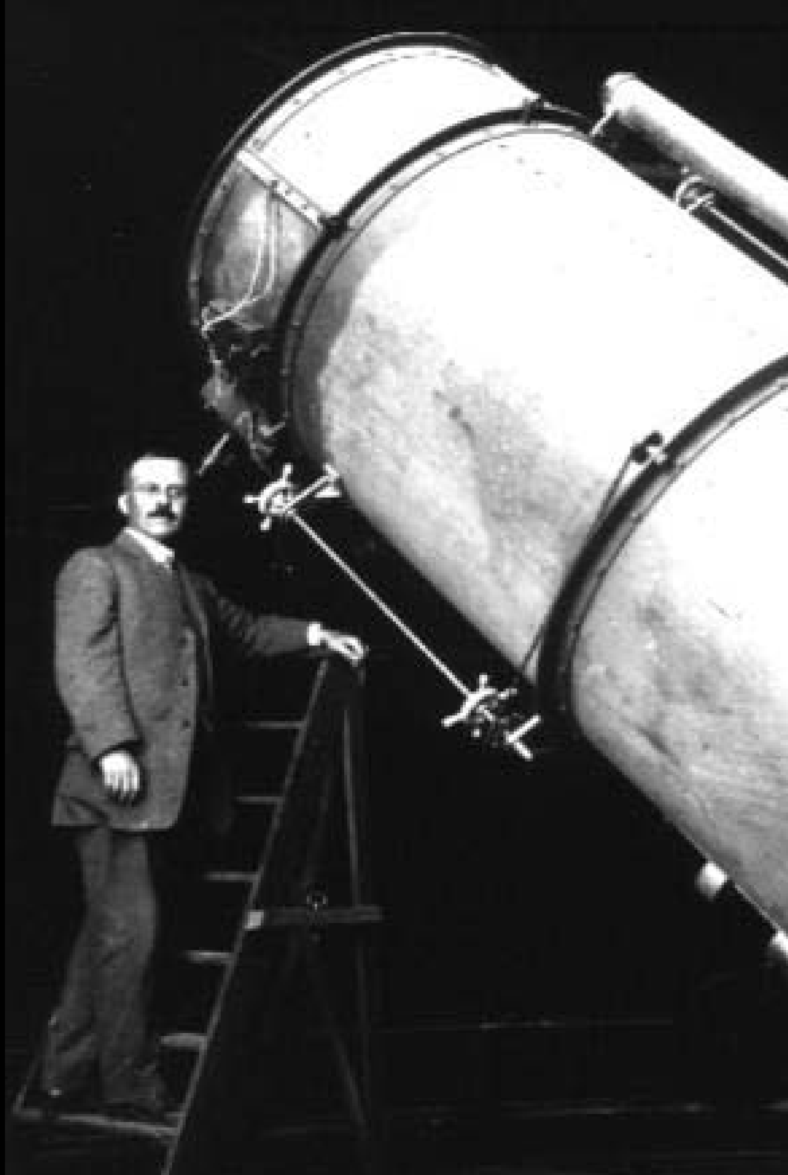
A view of the universe, circa 1903 A.D.

Kapteyn Universe

1) **Composition**: Starz' in the 'hood
2) **Arrangement**:



3) **Origin**: ?

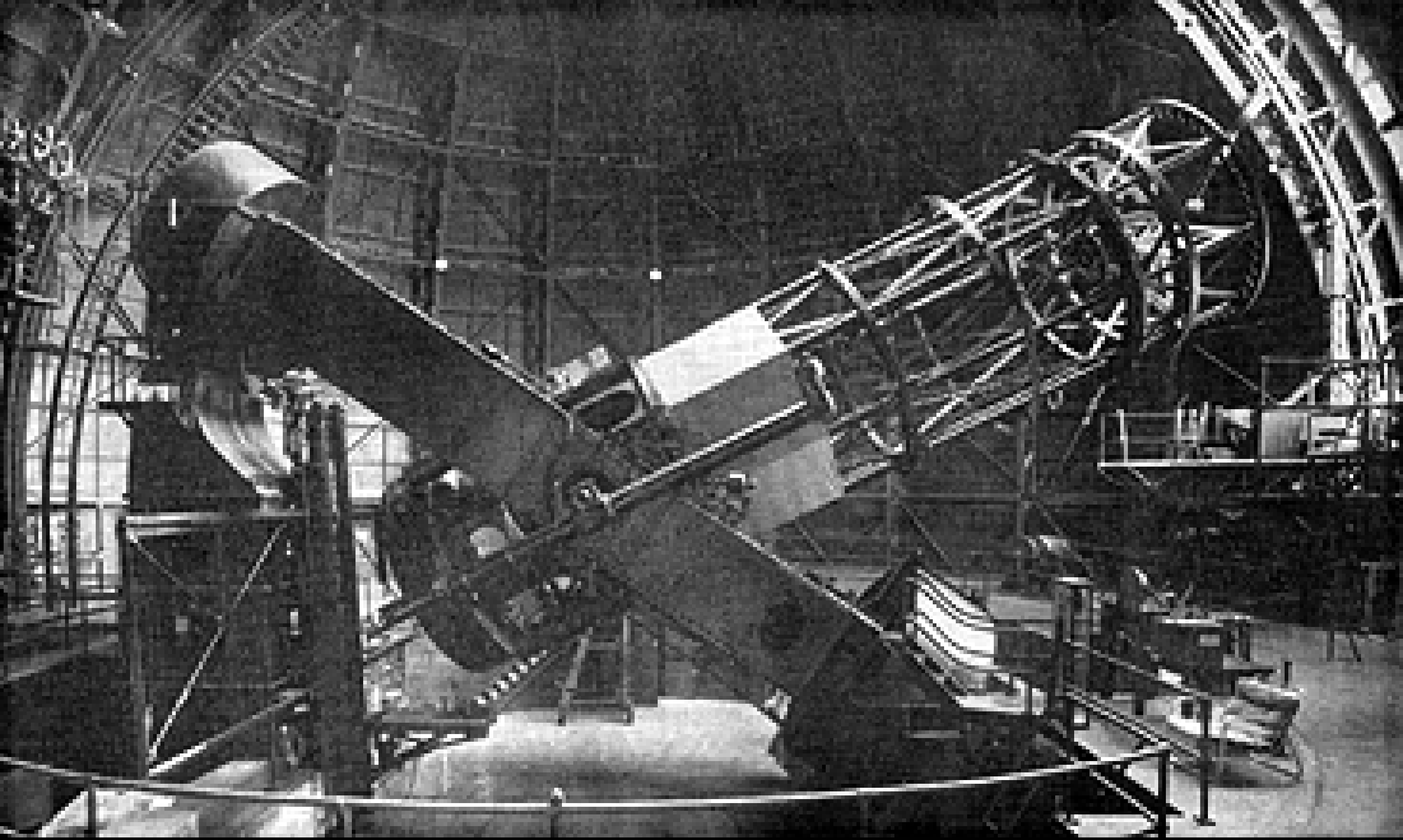


Heber Curtis
1872 - 1942

Harlow Shapley
1885 - 1972

Edwin Hubble
1884 - 1953

University of Chicago 1909 National Champions



100-inch Hooker Telescope on Mt. Wilson

Hubble's Hooker Chair

Einstein at Yerkes, May 6, 1921

ANDROMEDA
GALAXY


~~N~~
VAR!
N
6-Oct
1923
N